AD NUMBER

AD863679

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies only; Administrative/Operational Use; 5 Dec 1969. Other requests shall be referred to the Commanding Officer, Naval Ordnance Lab., White Oak, MD.

AUTHORITY

USNOL ltr, 12 Dec 1972

ANALYSIS AND CORRELATION OF UNDERWATER EXPLOSION DATA AT NOL

By:
Donald E. Phillips

ABSTRACT: The methods used in acquiring, analyzing, and correlating data from underwater explosion tests are discussed. These include preliminary tests of small (1-lb) charges of new compositions using diaphragm gages, and tests of larger charges using more elaborate instrumentation. Methods for computing equal weight and equal volume ratios, and for computing equivalent weights, are presented. The possible variation of these values with distance will be discussed, and methods of making estimates from limited data will also be given.

Underwater Explosions Division
U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

NOLTR 69-192 5 December 1969

Analysis and Correlation of Underwater Explosion Data at NOL

This report summarizes many of the aspects of the methods used at NOL to analyze and correlate underwater explosion shock wave data, the ultimate goal being the evaluation of new explosives for use in Navy weapons. It is a slightly expanded version of a paper of the same title presented at the Panel O-2 meetings of TTCP, held 8-12 Sep 1969, at the Explosives Research Development Establishment, Waltham Abbey, Essex, England. Preparation of the paper and report were performed under ORDTASK ORD 332 006 092-1/UF 17 354 304, Explosives U/W Research and Technology.

GEORGE G. BALL
Captain, USN
Commander

C. J. ARONSON
By direction

CONTENTS

		page
1.	Introduction	1
2.	Background	1
3.	Data Analysis	
	3.1 Record Analysis	2
	3.2 Similitude Equations	2
4.	Correlation of Data	
	4.1 Computation of Equal Weight Ratios	3
	4.2 Computation of Equal Volume Ratios	5
	4.3 Computation of Equivalent Weight	6
5.	Estimates of Variability	7
6.	Future Plans	8
7.	Summary	9

ILLUSTRATIONS

Figure	Title	
1	Diaphragm Gage Test Array	10
2	Typical Large Charge Gage Array	11
3	Method for Determining P_m	12
4	Method for Computing Impulse and Energy	13

TABLES

Table	Title	
1	Percentage Change in Ratios for a Five Percent Change in Similitude Exponent	8

REFERENCES

(a) Cole, R. H.; "Underwater Explosions"; Princeton University Press, Princeton, New Jersey; 1948; Unclassified
(b) Thiel, M. A., "Revised Similitude Equations for the Underwater Shock Wave Performance of Pentolite and HBX-1"; NAVWEPS Report 7380; 1 Feb 1961; Unclassified

REFERENCES con't.

(c) Coles, J. S., et al; "Shockwave Parameters from Spherical HBX and TNT Charges Detonated Under Water"; NAVORD Report 103-46; Dec 1946; Unclassified

1. Introduction

The assessment of the underwater performance or output of a new explosive composition is of utmost importance in determining its suitability for use in Navy weapons. Depending on its intended use, this assessment is made in various forms, such as equal weight or equal volume ratios, or expressed in terms of an equivalent weight of some standard high explosive, usually HBX-1 or Pentolite.

These various methods are often used with the results appearing only as a number (Explosive X is so much better than HBX-1). The manner in which this number is arrived at, however, is not well known, nor are its limitations. It is the purpose of this paper to summarize these various assessment procedures, to derive the necessary equations, and to show the possible dependence of such values on distance from the charge. Methods of data gathering and analysis will also be discussed.

2. Background

In the development of a new explosive composition, initial underwater tests are usually made with 1-lb charges, using diaphragm gages to determine the underwater performance (see Figure 1). This method is used for several reasons. First, it requires relatively small amounts of explosive, which for new compositions can be quite expensive. Second, a large number of compositions can be rapidly evaluated, as both the rate of firing and rate of analysis are quite high. Use of such a test procedure, however, has its limitations. Initiation problems for small charges, especially insensitive compositions, can give erroneous results. Also, the diaphragm gage measures only one shock wave parameter, the energy flux density. Other important parameters, such as peak pressure, time constant, and impulse are not measured. Finally, measurements are made at only one distance, which, if a dependence on distance exists, can be somewhat misleading if attempts are made to apply these results beyond the purpose for which they were intended.

Firing of 1-lb charges, if the data are properly used, thus serves as a valuable screening procedure. It also has considerable value in studying the detonation chemistry of new explosives (such as in studies of boostering and charge density) and in studies of various enhancement techniques (such as charge separation). However, it is beyond the scope of this paper to discuss these in any detail.

Once an explosive shows promise in such programs, larger charges are fired and more detailed shock wave measurements obtained. Charge weights may vary from 10 lb up to actual warhead size, perhaps as great as 1000 lb. For these tests, piezoelectric gages are used to obtain pressure-time histories at several distances from the explosive charge. A typical charge-gage rig is shown in Figure 2. Recording is accomplished using either oscilloscopes where the trace is recorded photographically, or magnetic tape recorders. Generally gages are located at reduced distances ($W^{1/3}/R$) ranging from 0.72 to 0.072 $lb^{1/3}/ft$. This corresponds to pressure levels of from about 16,000 psi to 1200 psi.

3. Data Analysis

3.1 Record Analysis. The pressure-time records are analyzed for values of peak pressure, time constant, impulse, and energy flux density using a high speed digital computer. If the recordings are made on magnetic tape, the FM records are digitized electronically. Film records are digitized using a Telereadex x-y film reader. The computer program extrapolates the pressure-time curve back to zero time to obtain the true peak pressure. A best line through the log pressure vs time data is obtained (using the method of least squares) over a range of approximately one time constant (i.e., $0 \leq t \leq \theta$) as illustrated in Figure 3. The true peak pressure represents the $t = 0$ intercept of this line; the time constant is the negative reciprocal of the slope of the line. The initial time $t = 0$ is determined using one-half the rise time of the trace* The computer program, developed by R. S. Price of NOL, exercises considerable discrimination in the selection of valid data points used in the fitting so as to minimize the effect of gage overshoot and noise. Impulse and energy flux density are computed by summing values of average pressure (or pressure squared) multiplied by Δt, where Δt is the time interval between successive data points. This is illustrated in Figure 4. For each record, about 40 data points are used in obtaining the fitted line and approximately 150 points are used to determine impulse and energy flux.

The program, it should be stated, is a "working model". It is subject to change as needs arise or as analytical methods change. One improvement currently desirable is some mathematical "goodness-of-fit" indication, such as the standard deviation (in percent) of the pressure data from the best straight line.

3.2 Similitude Equations. Based on several years of gathering experimental data, it has been found that these parameters can conveniently be expressed as functions of weight and distance by means of similitude equations. The general forms of these equations are (reference a):

Peak Pressure: $$P_m = C_P \left(\frac{W^{1/3}}{R}\right)^{\alpha_P} \quad (1)$$

Time Constant: $$\theta = C_\theta W^{1/3} \left(\frac{W^{1/3}}{R}\right)^{\alpha_\theta} \quad (2)$$

Energy Flux Density: $$E = C_E W^{1/3} \left(\frac{W^{1/3}}{R}\right)^{\alpha_E} \quad (3)$$

Impulse : $$I = C_I W^{1/3} \left(\frac{W^{1/3}}{R}\right)^{\alpha_I} \quad (4)$$

where:

P_m = peak pressure, psi

θ = time constant, msec

E = energy flux density, in-lb/in^2

*The rise time of the trace is defined as the time interval between the trace leaving the baseline and the maximum pressure being obtained.

I = impulse, psi-sec

W = charge weight, lb

R = distance or standoff from the charge, ft

C = coefficient characteristic of a particular explosive

α = exponent of the similitude equation, also in general characteristic of a given explosive

(subscripts,(P, θ, E, I)refer to the appropriate parameter).

For a given experimental program, similitude equations are also obtained using the digital computer by applying least squares fits to the experimental data. Because the data sample is small (perhaps only four shots of each explosive having been fired), these are not the similitude equations for a given explosive and are not in themselves intended for use in damage studies. Rather, they form the basis from which the various comparisons are subsequently made. Generally, the fits are made in reduced form of the similitude equations using values of P_m, $\theta/W^{1/3}$, $I/W^{1/3}$, and $E/W^{1/3}$ to facilitate comparisons where weights are unequal, and for future use in developing final similitude equations for a composition utilizing data from several charge weights.

4. Correlation of Data

Once the pressure-time records have been analyzed for the shock wave parameters and the similitude equations obtained, the manner in which these parameters are used to compare the output of the new explosive relative to the standard depends on the intended use of the composition. It should be noted that these comparisons are made relative to data from standard charges fired in the same series, and not from the absolute similitude equations available for the standard, such as those in Reference (b). The most generally used comparisons are:

1) Equal Weight Ratio: The ratio of the outputs with respect to a particular parameter (peak pressure, time constant, impulse, or energy flux density) for equal weights of two explosives at the same distance. (This is of interest in the design of weight-limited weapons.)

2) Equal Volume Ratio: The ratio of outputs with respect to a particular parameter for equal volumes of two explosives as measured at the same distance. (This is of interest in the design of volume-limited weapons.)

3) Equivalent Weight Ratio: The ratio of weights of two explosives required to produce the same magnitude of a particular parameter at the same distance.

4.1 Computation of Equal Weight Ratios. Equal weight ratios describe the change of a given shock wave parameter of a new explosive compared with the standard explosive, for charges having the same weight. It is the ratio,

for example, of the peak pressure measured from an experimental charge to that measured from the standard, both at the same range and of the same weight. If D_{Wd} refers to the equal weight ratio, then

$$D_{Wd(P)} = \frac{P(x)}{P(s)} \tag{5}$$

$$D_{Wd(\theta)} = \frac{\theta(x)}{\theta(s)} \tag{6}$$

$$D_{Wd(I)} = \frac{I(x)}{I(s)} \tag{7}$$

$$D_{Wd(E)} = \frac{E(x)}{E(s)} \tag{8}$$

for:

$$W(x) = W(s) = W \tag{9}$$

$$R(x) = R(s) = R \tag{10}$$

(the subscript s refers to the standard explosive, the subscript x refers to the experimental explosive)

If the exponents of the similitude equations for the two explosives are not the same, no single value of equal weight ratio can be computed, as the ratio is then a function of weight and distance. This can be shown by substituting the right hand sides of the similitude equations for the experimental and standard explosives in Equation (5). For peak pressure:

$$P_m(x) = C_{P(x)} \left(\frac{W(x)^{1/3}}{R(x)}\right)^{\alpha_{P(x)}}$$

$$P_m(s) = C_{P(s)} \left(\frac{W(s)^{1/3}}{R(s)}\right)^{\alpha_{P(s)}}$$

Using Equations (9) and (10) for weight and distance and the above two equations, the following relationship for the equal weight ratio is obtained:

$$D_{Wd(P)} = \frac{P_m(x)}{P_m(s)} = \frac{C_{P(x)}}{C_{P(s)}} \cdot W^{(\alpha_{P(x)} - \alpha_{P(s)})/3} \cdot R^{\alpha_{P(s)} - \alpha_{P(x)}} \tag{11}$$

The form of the equations for energy flux density, time constant, and impulse will be the same as Equation (11), only the subscripts being different. Thus for energy flux, for example:

$$D_{Wd(E)} = \frac{C_{E(x)}}{C_{E(s)}} \cdot W^{(\alpha_{E(x)} - \alpha_{E(s)})/3} \cdot R^{\alpha_{E(s)} - \alpha_{E(x)}} \tag{12}$$

Equation (11) shows a dependence of the equal weight ratio on both charge weight and distance. However, as was mentioned in Section 2, for different charge weights, measurements are made at the same reduced distance, not at the same distance. Returning to equations (1) and (5), it can be seen that, at the same reduced distance, the magnitudes for each explosive, and thus the equal weight ratio, will be the same regardless of charge weight. Thus, from a practical standpoint, the important variation in the equal weight ratio is with distance.

If the exponents of the two similitude equations are equal ($\alpha_{P(x)} = \alpha_{P(s)} = \alpha_P$), then Equation (11) reduces to:

$$D_{Wd(P)} = \frac{P(x)}{P(s)} = \frac{C_{P(x)}}{C_{P(s)}} \qquad (13)$$

Likewise, the equal weight ratios for the other parameters can be expressed as ratios of the coefficients of the similitude equations, if the exponents of the two similitude equations are the same.

4.2 Computation of Equal Volume Ratios. The equal volume ratio, as the name implies, refers to the changed output observed in a particular parameter from an experimental explosive relative to a standard explosive, both charges having the same volume. Such a comparison has been of considerable interest in recent years as many of the new weapons systems are volume limited in the amount of explosive they can carry. Thus, letting D_{Vd} indicate the equal volume ratio,

$$D_{Vd(P)} = \frac{P(x)}{P(s)} \qquad (14)$$

where: $V(x) = V(s)$ (= volume, ft^3)
$R(x) = R(s)$

Equations for the other shock wave parameters similar to (6), (7), and (8) can also be developed for the equal volume ratio. The similitude equation can be expressed as a function of volume by replacing W with ρV. Thus

$$P(x) = C_{P(x)} \cdot \rho(x)^{\alpha_{P(x)}/3} \cdot \left(\frac{V(x)^{1/3}}{R}\right)^{\alpha_{P(x)}}$$

where: ρ = experimental density, lb/ft^3

For non-equal exponents, equations similar to (11) and (12) can be developed. Thus:

$$D_{Vd(P)} = \frac{C_{P(x)}}{C_{P(s)}} \cdot \rho(x)^{\alpha_{P(x)}/3} \cdot \rho(s)^{-\alpha_{P(s)}/3} \cdot V^{(\alpha_{P(x)}-\alpha_{P(s)})/3} \cdot R^{\alpha_{P(s)}-\alpha_{P(x)}} \qquad (15)$$

$$D_{Vd(E)} = \frac{C_{E(x)}}{C_{E(s)}} \cdot \rho(x)^{(1+\alpha_{E(x)})/3} \cdot \rho(s)^{-(1+\alpha_{E(s)})/3} \cdot V^{(\alpha_{E(x)}-\alpha_{E(s)})/3} \cdot R^{\alpha_{E(s)}-\alpha_{E(x)}} \quad (16)$$

For time constant and impulse, equations of the form of (16) are obtained. If the exponents are equal, these reduce to:

$$D_{Vd(P)} = \frac{C_{P(x)}}{C_{P(s)}} \cdot \left(\frac{\rho(x)}{\rho(s)}\right)^{\alpha_P/3} \quad (17)$$

$$D_{Vd(E)} = \frac{C_{E(x)}}{C_{E(s)}} \cdot \left(\frac{\rho(x)}{\rho(s)}\right)^{(1+\alpha_E)/3} \quad (18)$$

Equations for the equal volume ratios for time constant and impulse will have the same form as Equation (18). It is interesting to note the relationship between the equal weight and equal volume ratios if the exponents are the same. Comparing Equation (13) and (17), it can be seen that the equal volume ratio is equal to the equal weight ratio multiplied by the ratio of densities raised to an exponent. Such a relationship is of importance if it is necessary to compute one ratio from the other.

4.3 Computation of Equivalent Weight. It is often useful to the engineer or designer to have the comparison made in terms of the weight required to produce the same magnitude in a particular parameter. This is referred to as the equivalent weight, which for a given shock wave parameter expresses the number of pounds of a standard explosive required to give the same magnitude of that parameter at the same range as does a given weight of experimental explosive.

Letting W_{Dd} refer to the equivalent weight ratio, then

$$W_{Dd(P)} = \frac{W(s)}{W(x)} \quad (19)$$

for

$$P_m(s) = P_m(x) = P_m \quad (20)$$

$$R(s) = R(x) = R \quad (21)$$

Likewise, W_{Dd}'s can be expressed for equal values of θ, I, and E. Inserting the right sides of the similitude equations for $P_m(s)$ and $P_m(x)$ in Equation (20) and solving for $W(s)$, the following relationship is obtained:

Peak Pressure:

$$W(s) = \left(\frac{C_{P(x)}}{C_{P(s)}}\right)^{3/\alpha_{P(s)}} \cdot R^{3\left(1 - \frac{\alpha_{P(x)}}{\alpha_{P(s)}}\right)} \cdot W(x)^{\frac{\alpha_{P(x)}}{\alpha_{P(s)}}} \quad (22)$$

Energy flux density:

$$W(s) = \left(\frac{C_{E(x)}}{C_{E(s)}}\right)^{\frac{3}{1+\alpha_{E(s)}}} \cdot R^{\frac{3(\alpha_{E(s)} - \alpha_{E(x)})}{1+\alpha_{E(s)}}} \cdot W(x)^{\frac{1+\alpha_{E(x)}}{1+\alpha_{E(s)}}} \qquad (23)$$

(For impulse and time constant, the above form of the equation is also obtained, only the subscripts being different.)

For equal exponents, these equations reduce to:

Peak pressure:

$$W(s) = \left(\frac{C_{P(x)}}{C_{P(s)}}\right)^{3/\alpha_P} \cdot W(x) \qquad (24)$$

Energy flux density:

$$W(s) = \left(\frac{C_{E(x)}}{C_{E(s)}}\right)^{3/(1+\alpha_E)} \cdot W(x) \qquad (25)$$

(Again, time constant and impulse have the same form as Equation (25).)

For the case of equal exponents, it should be noted that the equivalent weight ratio is equal to the equal weight ratio raised to an exponent.

5. Estimates of Variability

We have attempted in Section 4 to define the various comparison methods and to show that, if non-equal exponents exist between the similitude equations for the two explosives, these ratios will vary with distance. The engineer or weapons designer, however, is not interested in such complex relationships. He needs a single value which tells him how much better one explosive is than another. An average value for each parameter, obtained over the range of distances for which measurements were obtained, appears to best answer his needs, except possibly in rare design problems where the designer is trying to optimize a system for a particular pressure or distance level. In such instances the appropriate values should be used instead of the average over the range of measurements. It is important in using an average to realize its limitations, a precaution that is often neglected or misunderstood.

To see how much variability migh occur in such an average, let us consider the effect of a five percent difference in exponent for the two similitude equations for each parameter. This seems to be a reasonable estimate as differences of this magnitude have been observed in experimental programs. It may possibly be low for the time constant, where exponents from -0.18 to -0.29 have been observed (a difference of 45 percent) (references b and c).

The computations were made using the similitude equations for HBX-1 as given in reference (b) for the standard, and increasing these exponents by five percent for the experimental explosive. The exponents used then are:

$\alpha_{P(s)} = 1.15$ $\qquad$ $\alpha_{P(x)} = 1.21$

$\alpha_{\theta(s)} = -0.29$ $\qquad$ $\alpha_{\theta(x)} = -0.305$

$\alpha_{I(s)} = 0.85$ $\qquad$ $\alpha_{I(x)} = 0.91$

$\alpha_{E(s)} = 2.00$ $\qquad$ $\alpha_{E(x)} = 2.10$

$\rho(s) = 107 \text{ lb/ft}^3$ $\qquad$ $\rho(x) = 118 \text{ lb/ft}^3$

Table 1 shows the percentage change in the various ratios over the range of reduced distances discussed in Section 2. Note that both peak pressure and energy flux density show the greatest variation. What this table says, for instance, is that based on peak pressure, the equivalent weight ratio will show a difference of 29 percent between that needed to produce the required magnitude at the position where the curves are matched and that needed at another position where the exponents have caused the curves to diverge, for the same weight of experimental explosive.

TABLE 1

Percentage Change in Ratios for a Five Percent Change in Similitude Exponent*

Parameter	D_{Wd}	D_{Vd}**	W_{Dd}
Peak Pressure	13	5	29
Time Constant	4	1	16
Impulse	9	3	14
Energy Flux Density	20	8	20

The variation shown in Table 1 for the equal volume ratio is somewhat misleading in that, as can be seen in Equations (15) and (16), the difference in exponent affects density as well as distance. For the particular example chosen, the affect on density tended to cancel the effect on distance, so that somewhat smaller variations were obtained. That there is a combined effect, however, should be kept in mind.

6. Future Plans

The increased use of the digital computer has been illustrated in this discussion, as evidenced by its use in the analysis of the pressure-time records, in the fitting the resulting data to obtain the similitude equations, and in correlating the results. Currently, a computer program is being developed which, taking the basic information such as peak pressure, time constant, etc., obtains the required similitude equations and computes the various ratios discussed in this paper. It rejects bad data, gives estimates of the goodness

* Calculated over a range of reduced distances from 0.72 to 0.072 $\text{lb}^{1/3}/\text{ft}$.

** Density increase of 10 percent assumed.

of fit, and computes variations in the ratios. While the mathematical methods used are straightforward, use of the computer will greatly reduce the amount of time necessary to make such computations, allowing more complete comparisons to be made and making the results available much more rapidly than had previously been possible.

Currently, the largest problem is the digitization of the oscilloscope recorded pressure-time records, which still represent the bulk of the records obtained at NOL. Using the Telereadex, an experienced operator can digitize about four shots (48 records) per day. While this is a vast improvement over completely manual methods, it barely allows the analysis to keep up with the firing. Operator fatigue and scheduling problems for the machine permit only about three days a week of Telereadex time, or about 12 shots per week. Firing of 3 to 5 shots per day is not uncommon when small charge weights are used.

There are two possible solutions to this problem, both expensive. One is the procurement of a magnetic tape recorder having sufficient frequency response for use with small charges, thus eliminating the need for manual digitization. NOL is in the process of purchasing such a recorder; however, it will be available only on a limited basis for our regular testing programs. Therefore, in the event that this recorder will not be able to keep up with the data acquisition rate, we are surveying the market for machines that can increase our speed of digitizing the film records and reduce operator fatique.

7. Summary

We have attempted to show, at least briefly, how new explosives for possible underwater use are evaluated at NOL. Data collection, analysis, and correlation have been discussed. We have also tried to show how the increased use of computers in the analysis and correlation of data from underwater explosion measurements has greatly increased our ability to handle and correlate explosion data. Further improvements in our techniques undoubtedly will follow as increased use of the computer continues.

It has been shown that the various methods of comparing the free water output of new compositions, while useful, must be applied with caution, as it is likely that the correlation varies with distance. While it is helpful to give the engineer or weapons designer a single number with which to work, that this number may vary by as much as 30 percent (depending on the range of interest) has, in the past, not been fully appreciated.

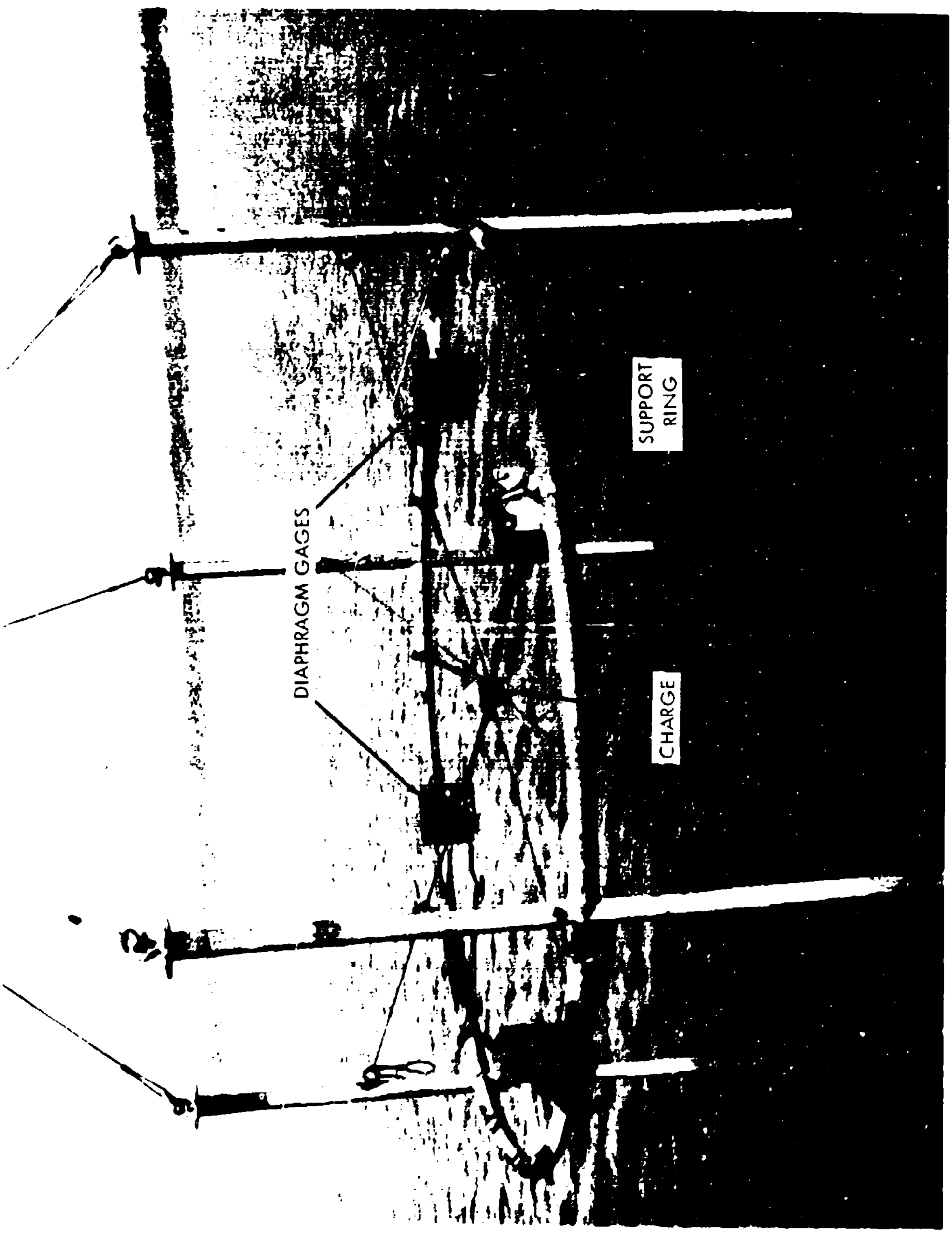

FIG. 1 DIAPHRAGM GAGE TEST ARRAY

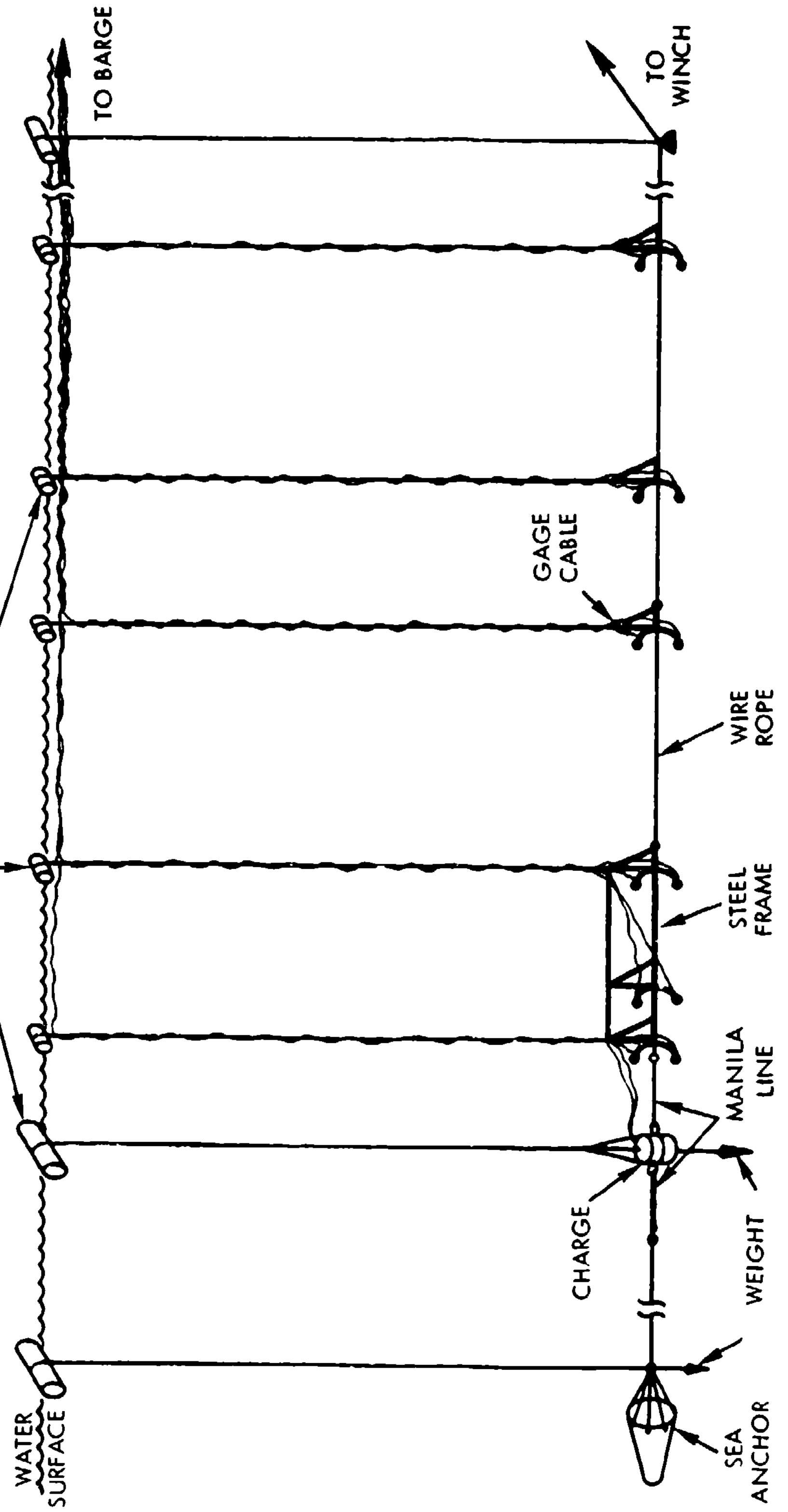

FIG. 2 TYPICAL LARGE CHARGE GAGE ARRAY

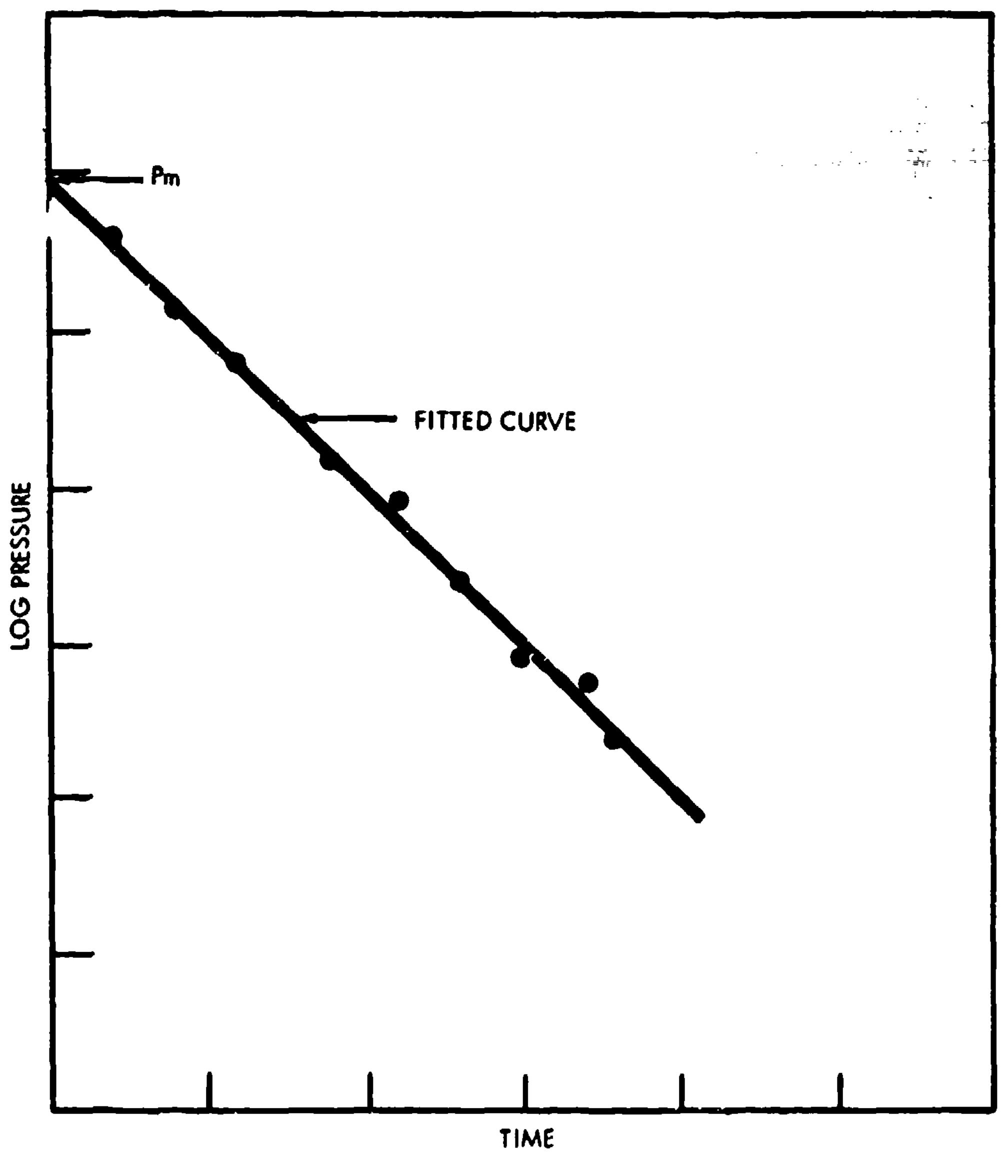

FIG. 3 METHOD FOR DETERMINING Pm

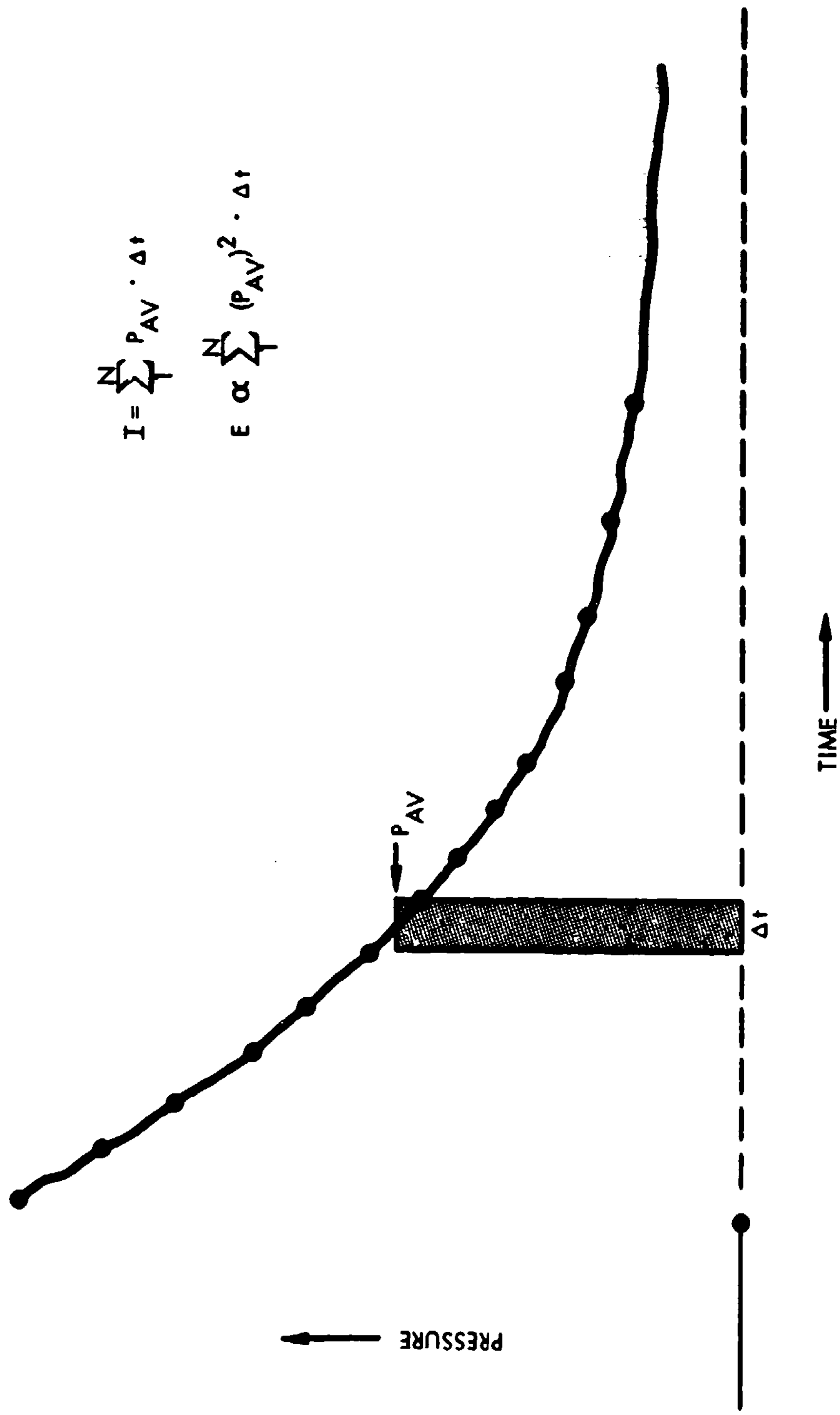

FIG. 4 METHOD FOR COMPUTING IMPULSE AND ENERGY

DISTRIBUTION LIST

	Copies
Chief of Naval Operations Washington, D. C. 20360 Attn: OP-75	1
Chief of Naval Research Washington, D. C. 20360 Attn: Code 408	1
Code 418	1
Code 466	1
Commander Naval Ordnance Systems Command Washington, D. C. 20360 Attn: ORD-033	1
ORD-034A	1
ORD-035	1
ORD-054111	2
ORD-05411	1
ORD-9132	2
ORD-0332 (Amster)	1
ORD-0332B (Dieter)	1
ORD-05511 (Miller)	1
Commander Naval Ships Systems Command Washington, D. C. 20360	2
Commander Naval Facilities Engineering Command Washington, C. C. 20360	1
Commanding Officer U. S. Naval Ordnance Station Indian Head, Maryland 20640 Attn: Library Division	1
Commanding Officer U. S. Naval Explosive Ordnance Disposal Facility Indian Head, Maryland 20640 Attn: Library Division	1
Commander Naval Weapons Laboratory Dahlgren, Virginia 22448 Attn: Experimental Officer	1

Commander
Naval Weapons Center
China Lake, California 93555
Attn: Technical Library 1

Commander
Naval Undersea Warfare Center
3202 E. Foothill Boulevard
Pasadena, California 91107 1

Director
Naval Research Laboratory
Washington, D. C. 20390 2

Commanding Officer & Director
Naval Ship Research & Development Center
Washington, D. C. 20007
Attn: Library 1
Dr. W. W. Murray 1

Commanding Officer & Director
Underwater Explosions Research Division
Naval Ship Research & Development Center
Portsmouth, Virginia 23709 1

Superintendent
U. S. Naval Postgraduate School
Monterey, California 93940 1

Commander
Naval Undersea Research and Development Center
San Diego Division
271 Catalina Boulevard
San Diego, Californis 92152 1

Commanding Officer
U. S. Naval Underwater Weapons
Research & Engineering Station
Newport, Rhode Island 02840 1

Commander
U. S. Naval Weapons Station
Yorktown, Virginia 23491
Attn: Research & Development Division 1

Commanding Officer
U. S. Navy Underwater Sound Laboratory
Fort Trumbull
New London, Connecticut 06321 1

Commanding Officer
U. S. Naval Air Development Center
Johnsville, Pennsylvania 18974 1

Commander U. S. Naval Oceanographic Office Washington, D. C. 20390	1
Commanding Officer and Director U. S. Naval Ship Research & Development Laboratory Panama City, Florida 32402	1
Commanding Officer Naval Civil Engineering Laboratory Port Hueneme, California 93041	1
Commanding Officer U. S. Naval Weapons Evaluation Facility Kirtland Air Force Base Albuquerque, New Mexico 87117	1
Chief of Research & Development Department of the Army Washington, D. C. 20310	2
Commanding General Material Command Headquarters Department of the Army Washington, D. C. 20315	2
Chief of Engineers Department of the Army Washington, D. C. 20315	
Attn: ENGNB	2
ENGEB	1
Commanding Officer U.S. Army Mobility Equipment R & D Center Fort Belvoir, Virginia 22060	2
Director Waterways Experiment Station Vicksburg, Mississippi 39181	
Attn: Technical Library	1
G. L. Arbuthnot	1
J. N. Strange	1
Commanding General Ballistic Research Laboratories Aberdeen, Maryland 21005	1
Commanding Officer Picatinny Arsenal Dover, New Jersey 07801	1

Commanding Officer
USA Signal R&D Laboratory
Fort Monmouth, New Jersey 07703
Attn: Technical Documents Center 1

Commanding Officer
Nuclear Defense Laboratory
Edgewood, Maryland 21010 1

Chief
AF Technical Applications Center
2525 Telegraph Road
Alexandria, Virginia 22300 1

Commander (OOAMA)
Hill Air Force Base
Ogden, Utah 84401
Attn: Ammunition Services Office 1

Commander (PGTRI)
Air Proving Ground Center
Eglin Air Force Base, Florida 32542 1

Commander
Norton Air Force Base
San Bernadino, California 92409
Attn: SMASB 1

Commander
Air Force Weapons Laboratory
Kirtland Air Force Base
Albuquerque, New Mexico 87117
Attn: (WLIL) 1

Director
Defense Research & Engineering
Washington, D. C. 20310
Attn: Technical Library 1

Director
Applied Physics Laboratory
Johns Hopkins University
Silver Spring, Maryland 20910 1

Director
Defense Atomic Support Agency
Washington, D. C. 20305 2

Director
Applied Physics Laboratory
University of Washington
Seattle, Washington 1

Director
Ordnance Research Laboratory
Pennsylvania State University
University Park, Pennsylvania 16802 1

Director
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543 1

Director
Scripps Institute of Oceanography
La Jolla, California 92037 1

Director
Hudson Laboratories
Columbia University
145 Palisade Street
Dobbs Ferry, New York 10522 1

Director
Lawrence Radiation Laboratory
University of California
Livermore, California 90024
Attn: Technical Information Division 2

Director
Los Alamos Scientific Laboratory
University of California
P. O. Box 1663
Los Alamos, New Mexico 87544
Attn: Dr. D. P. MacDougall 1

NASA Scientific & Technical Information Facility
P. O. Box 33
College Park, Maryland 20740 1

Sandia Laboratories
P. O. Box 5800
Albuquerque, New Mexico 87115
Attn: Technical Libraries, 3421 1

Sandia Corporation
P. O. Box 969
Livermore, California 94551 1

URS Corporation (DA-49-146-XZ-122)
1811 Trousdale Drive
Burlingame, Califronia 94011
Attn: Kenneth Kaplan 1
Deputy Director

Defense Documentation Center
Cameron Station
Alexandria, Virginia 22314
Attn: TIPDR 20

Chief of Naval Material
U. S. Naval Ordnance Laboratory
White Oak, Silver Spring, Maryland 20910
Attn: ASW-900 1

Officer in Charge
Naval Weapons Center, Corona Laboratories
Corona, California 91720 1

Commanding Officer
SEAL Team Two
Amphibious Force
U. S. Atlantic Fleet
U. S. Naval Amphibious Base
Norfolk, Virginai 23512 1

Lovelace Foundation for Medical Education & Research 1
5200 Gibson Boulevard, S.E.
Albuquerque, New Mexico 87108

Southwest Research Institute 1
8500 Culebra Road
San Antonio, Texas 78228

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) U. S. Naval Ordnance Laboratory White Oak, Silver Spring, Maryland 20910	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

Analysis and Correlation of Underwater Explosion Data at NOL

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

Donald E. Phillips

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
5 December 1969	14	3

8a. CONTRACT OR GRANT NO. ORDTASK ORD 332 006 092-1/UF 17 354 304 b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NOL - TR 69-192 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Each transmittal of this document outside the agencies of the U.S. Government must have prior approval of NOL.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Ordnance Systems Command

13. ABSTRACT

The methods used in acquiring, analyzing, and correlating data from underwater explosion tests are discussed. These include preliminary tests of small (1-lb) charges of new compositions using diaphragm gages, and tests of larger charges using more elaborate instrumentation. Methods for computing equal weight and equal volume ratios, and for computing equivalent weights, are presented. The possible variation of these values with distance will be discussed, and methods of making estimates from limited data will also be given.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Explosives Underwater Explosions Evaluation Data Analysis						